Kinetics of phase separation of magnetic colloids in rotating magnetic fields

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This work is focused on the experimental and theoretical study of the phase separation of a magnetic nanoparticle suspension under rotating magnetic field in a frequency range, $5 \leq \nu \leq 25$ Hz, relevant for several biomedical applications, as non-invasive thrombosis treatment by rotating microaggregates. The phase separation is manifested through appearance of needle-like dense particle aggregates synchronously rotating with the field. Their size progressively increases with time due to absorption of individual nanoparticles (aggregate growth) and coalescence with neighboring aggregates. Unlike the case of the permanent magnetic field, the aggregate growth is enhanced by convection of nanoparticles with respect to rotating aggregates, and the maximal aggregate length, $L_{max} \propto \nu^{-2}$, is limited by fragmentation arising as a result of their collisions. Experimentally, aggregate growth and coalescence occur at similar timescales, ~1 min, weakly dependent on the field frequency. The proposed theoretical model, based on the population balance equation and diffusion boundary layer approach, provides at least semi-quantitative agreement with experiments on integral characteristics (average aggregate size, volume fraction, number density), aggregation timescale and size distribution function, without any adjustable parameter. In general, our system exhibits behaviors common with condensation-driven aggregation in molecular liquids or polymers, convection-diffusive particle transport during particle filtration, coalescence and fragmentation of colloidal aggregates, liquid drops or bubbles.